04 Apr 1995, 2:30 pm - 3:30 pm

Microconcrete Subjected to Static and Dynamic Compression Loadings

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Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
April 2-7, 1995; Volume III, St. Louis, Missouri

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Paper No. 2.03

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SYNOPSIS: The object of our paper is to consider the influence of the strain rate as a particularly important factor, and to achieve a model describing the static and dynamic behaviour of the microconcrete. The specimens have been loaded in compression at strain - rates ranging from 0.0001 to 800 (1/s). The results are discussed and compared with those available in the literature.

INTRODUCTION

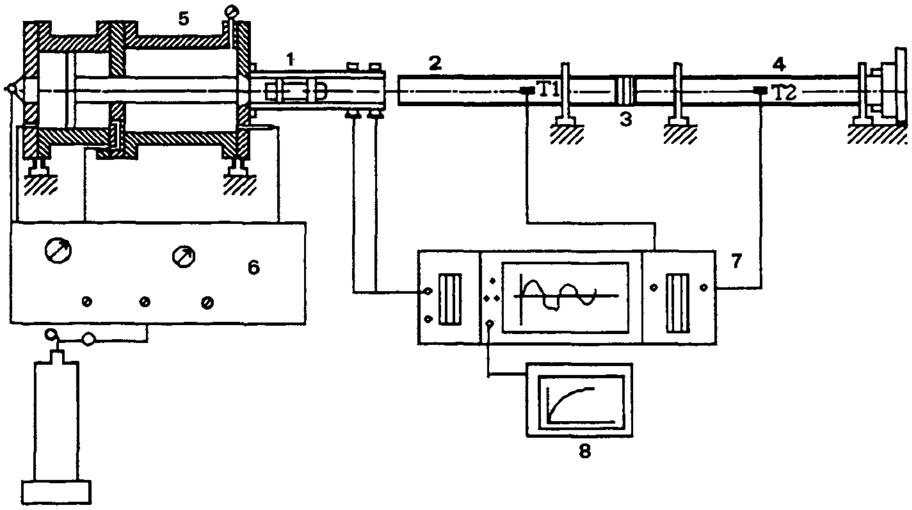
Microconcrete is used in laboratories to study on models the strength, deformations and modes of failure of prototype elements in reinforced concrete. It can give a real representation of the behaviour of concrete structures which would be subjected to dynamic loads during their lifespan. These dynamic loads may arise from impact of ballistic or tornado generated missiles, impulses due to air blasts or wind gusts, as well as from earthquakes.
Considering the results obtained from literature: Kumar et al. (1980), Kavyrchine (1980) and the paper entitled "Survey on Microconcrete" (1975), it can be said that because of strength-rheological properties, the microconcrete can be classified among the usual construction materials. We notice that the majority of these investigations are made for microconcrete subjected to static loading. However, knowledge on the high strain rate behaviour of microconcrete, which has been very limited, is of the utmost importance in the design of structures subjected to dynamic loadings and in applications, such as the very thin slabs, the columns, and the beams where the reinforcement is very dense (Critical Regions).
In this paper, strain rate effects on the mechanical behaviour of microconcrete have been studied; the dynamic testing (100-800 (1/s)) is done by the split-HOPKINSON pressure bar method and the intermediate rates (0.0001 to 1.5 (1/s)) are performed on a hydraulic testing machine "MTS". The results show that as the strain rate increases the compressive strength, elastic modulus increase.
A constitutive equation describing the behaviour of microconcrete at low and high strain rates is proposed.
A power law relationship between compressive strength and strain rate is developed.

EXPERIMENTAL PROGRAM

The microconcrete mixing was designed to acquire a static compressive strength at 28 days equal to 35 (Mpa). The mix proportins for this microconcrete ar as follows (weight per cubic meter):

coarse sand (1.5-5.0mm)	950 kg
medium sand (0.5-1.6mm)	220 kg
fine sand (0.0-0.5mm)	410 kg
normal portland cement	450 kg
water	225 kg.

The static and dynamic test specimens are cast and cured by identical methods until one day before the tests (slump-test = 55mm, moist room at a temperature of 20 + 2C° and a relative humidity of 95 + 5%).
The tests were made on 40mm high x 20mm diameter cylinders. All the tests were carried out at an age of 28 days and ambiant temperature.
The experimental program is composed of a number of tests; the intermediate testing was done by a hydraulic machine "MTS" and the high strain rates were performed with a split Hopkinson pressure bar (fig. 1.) (tests based on the propagation of one-dimensional elastic stress wave in bar); which has been described clearly in literature; Kolsky (1953), Hwaija (1991), Chiem et al. (1990).
Figure 2. shows the experimental compressive stress-strain curves at different strain rates; it is shown that compressive strength increases with increasing strain rate. The values of strain at peak and elastic modulus show a great sensitivity to strain rate. We can notice that the microconcrete specimens exhibite rapidely decreasing stress after exceeding the peak stress at the high strain rate range (brittle failure), whil there is a reduction in slop of the descending branche of the stress-strain curve at the static and intermediate rates (0.0001 to 1.5 (1/s)).
Figure 3. shows the strain rate sensitivity of the peak stress of microconcrete specimens for the intermediate and high strain rate ranges (experimental tests).
The failure modes of the specimens are shown



1. Projectile 2. Incident bar 3. Specimen
4. Transmission bar 5. Launching system
6. Pressure command pannel recording system 7. Apparatus signal
8. Data processing.

Fig. 1. Equipments for high strain-rate compression tests.

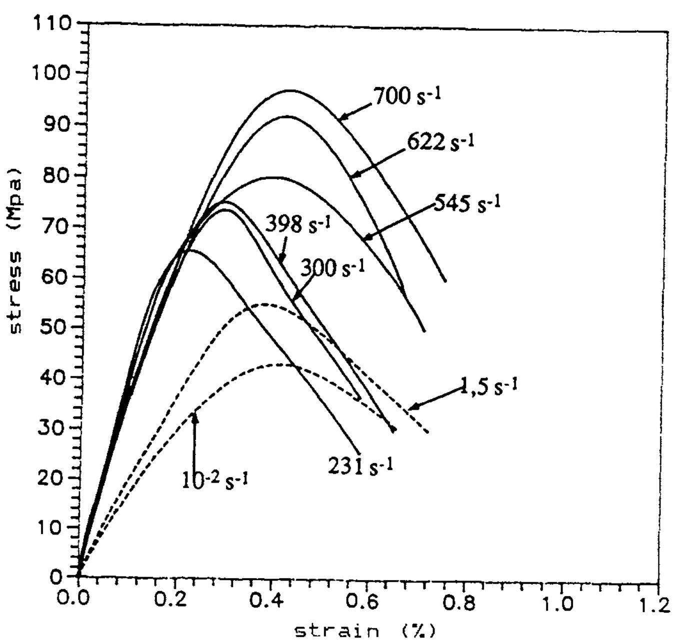


Fig. 2. Experimental stress-strain curves at different strain rates.

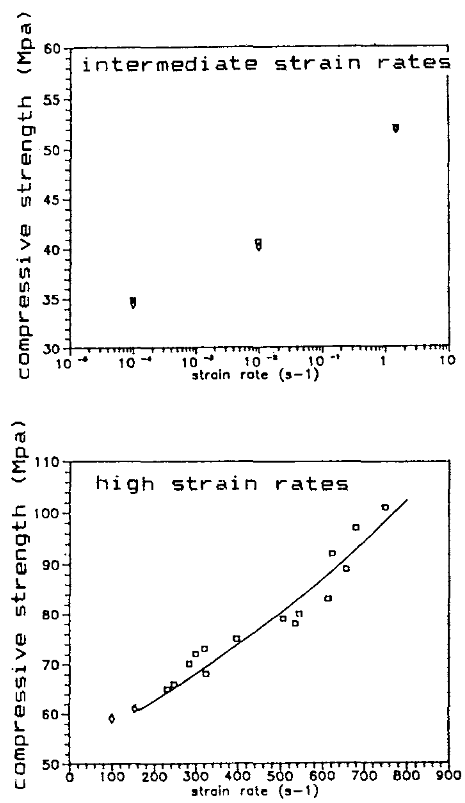


Fig. 3. Effects of stain rate on the compressive strength of microconcrete specimens.

in figure 4., according to the type of loading:
Intergranular fracture: static loading.
Mixed fracture: intermediate rates.
Intragranular fracture: high strain rates.
From optical microscope observations of the microstructure, it is found that the cracks traverse through the grains and the matrix of cement, and many grains are broken in the case of dynamic loading (brittle failure).

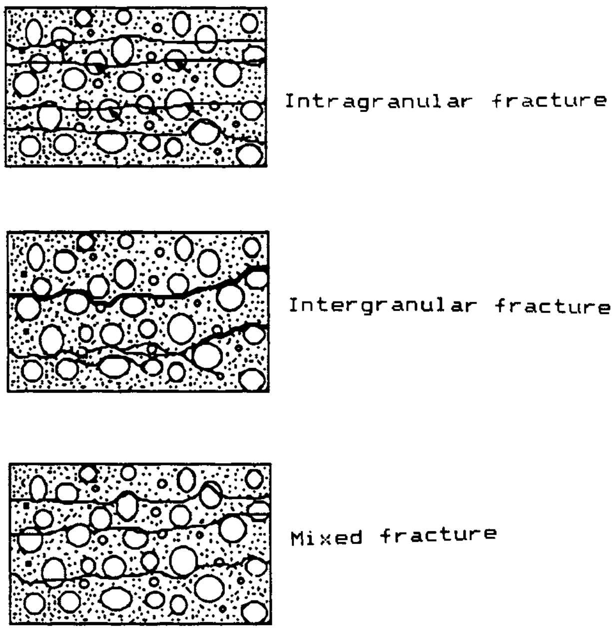


Fig. 4. Failure modes of the microconcrete specimens.

ANALYTICAL PROGRAM

It is desirable to define a general law of behaviour of the microconcrete by an analytical formula counting on the phenomena observed in dynamic test results: static parameters and strain rate.
The analytical expression connecting the stress with strain is defined as below:

$$\sigma = \frac{\varepsilon}{A_d + B_d.\varepsilon + C_d.\varepsilon^2 + D_d.\varepsilon^3}$$

(A_d,B_d,C_d,D_d) : dynamic parameters

$A_d = [(G_3.\varepsilon_0)/(G_2.f_c)]A_s$

$B_d = [1/(G_2.f_c)]B_s$

$C_d = [1/(G_2.f_c.G_3.\varepsilon_0)]C_s$

$D_d = \{1/[G_2.f_c.(G_3)^2.(\varepsilon_0)^2]\}D_s$

$G_2 = f_{cd}/f_{cs}$, $G_3 = \varepsilon_{0d}/\varepsilon_{0s}$

G_2 represents the strain rate effects on the peak stress
G_3 takes into account the strain rate effects on the strain at peak stress

σ : microconcrete compressive stress

ε : microconcrete compressive strain

f_c : 28-day static compressive strength

ε_0 : static strain at f_c

f_{cs} : static compressive strength

ε_{0s} : static strain at

f_{cd} : dynamic compressive strength

ε_{0d} : dynamic strain at f_{cd}

$\dot{\varepsilon}$: strain rate (1/s)

(As,Bs,Cs,Ds): static parameters which take into account the effect of the static compressive strength of the microconcrete (Fig. 5.); Hwaija (1991).
From the experimental stress-strain curves obtained, we have evaluted the dynamic compressive strength and the corresponding strain.
The equations of the best-fit curves connecting the dynamic compressive strength of microconcrete and corresponding strain, with the strain rate are as follows (28-day static compressive strength = 35 Mpa):

$f_{cd} = 50{,}40\,\dot{\varepsilon}^{1/24}$ (MPa), $\varepsilon_{0d} = 0{,}3837-0{,}0239\log\dot{\varepsilon}$ (%), $10^{-4} < \dot{\varepsilon} < 1{,}5\ s^{-1}$.
$f_{cd} = 11{,}60\,\dot{\varepsilon}^{0{,}31}$ (MPa), $\varepsilon_{0d} = 0{,}1946\ \mathrm{EXP}(0{,}001144\,\dot{\varepsilon})$, $2.10^2 < \dot{\varepsilon} < 10^3\ s^{-1}$.

These dynamic values with static parameters (As,Bs,Cs,Ds) can be used to determine the dynamic parameters (Ad,Bd,Cd,Dd) of the proposed model. Hence the entire stress-strain curve can be predicted.
Figure 6. shows a comparison between experimental and analytical stress-strain curves, at various strain rates, for a microconcrete show a static compressive strength at 28 days of the order of 35 (Mpa). (As=0.405; Bs=1.562; Cs=-2.340; Ds=1.373).

DISCUSSION AND COMPARISONS

A comparison of results obtained from different studies; Hughes (1972), Dilger (1984), Muria (1986), Soroushian et al. (1986a,b), with our work is presented in figure 7., where the ultimate strength ratio versus strain rate is plotted.
Test results show that strain at peak stress decreases with increasing strain rate from 0.0001 to 1.5 (1/s) (intermediate range). However, at high strain rate, we can notice that tends to increase as the strain rate increases from 100 to 800 (1/s) (high strain rates) (see Fig. 2.).
Concerning the elastic modulus, it is shown that the value of this modulus is nearly constant at the high strain rates, while that of intermediate range is much more rate-sensitive.

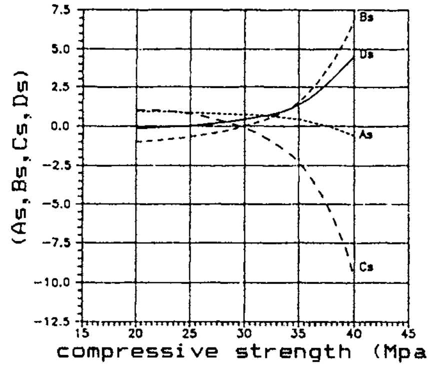


Fig. 5. Variation of the static parameters with the compressive strength.

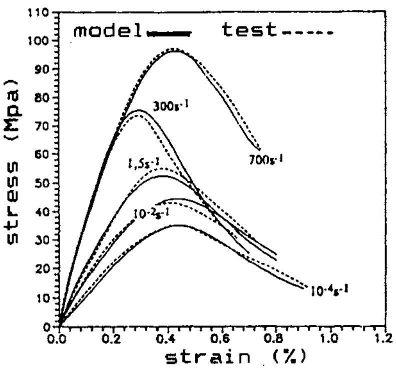


Fig. 6. Analytical and experimental stress versus strain curves at different strain rates.

According to the hypotheses built on the explanation of the phenomenon of the fracture of brittle materials (concrete, rocks, etc...), various approachs (Grady (1981), Krajcinovic (1981), Suaris (1984)), have been developed in order to predict the strain-rate sensitivity of the fracture strength (tension, flexural, compression) and to achieve analytical equations describing the behaviour of these materials under static and dynamic loadings. These models are calibrated using test data (Suaris (1985), Bicanic (1983)).
Morever, to achieve measurement of the strain-rate sensitivity of the fracture strength, several researchers have developed expressions which are based on the brittle fracture mechanics (role of inertia): Evans (1974), Grady et al. (1979,1980), Lankford (1981a,1982), Kipp et al.(1980).
It is evident from our test results that the compressive strength of microconcrete is dependent on strain rate. This rate dependence can be explained and expressed using a power law: $\sigma_f \,\alpha\, \dot{\varepsilon}^{1/1+n}$

where n is a material-dependent constant.

The value of n appears to decrease with the strain rate. Results obtained by Suaris (1982,1983) over a strain rate varying from 0.000001 to 1 (1/S) indicate a decrease in the value of n from 47 to 16. At high strain rates (10 to 100000 (1/s)), there is a cube-root relation for concrete and rocks: CEB (1988), Lankford (1981b).

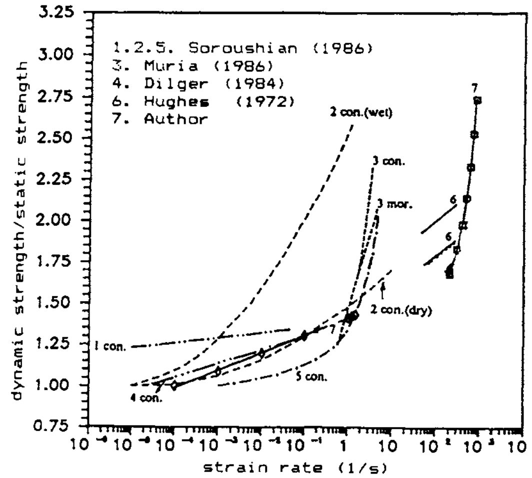


Fig. 7 Comparison of the strain-rate sensitivity (various studies).

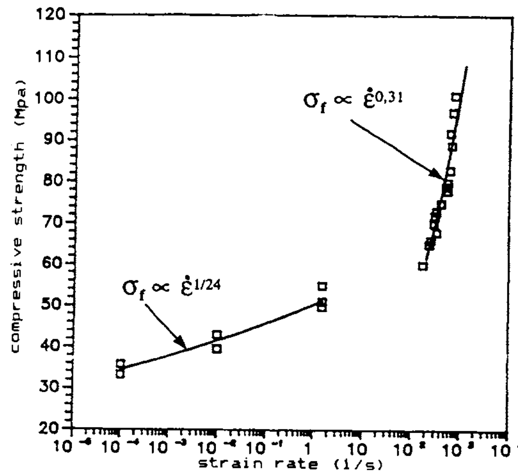


Fig. 8 Strain-rate dependence of compressive strength of microconcrete.

Figure 8. shows the variation of the compressive strength of microconcrete (analytical and experimental data) with strain rate from 0.0001 to 1000 (1/s). We can notice, at the intermediate range, that n=23. However, that is predicted to be about 2 at the high strain rates (Hwaija (1990)).

CONCLUSIONS

On the basis of our experimental results, it can be concluted that the dynamic compressive strength and elastic modulus of microconcrete are observed to be significantly greater than measured quasi-statically (strain rate = 0.0001 (1/s)). The ultimate compressive strength and elastic modulus ratios are given as below:

Strain rate (1/s):	0.0001	0.01	1.5	300	800
ultimate ratio( ):	1.0	1.2	1.5	1.9	2.6
ultimate ratio( ):	1.0	1.4	2.0	3.6	3.9

Consequently, the study of strain-rate sensitivity can contribute to safe an economical design of concrete structures subjected to dynamic loading.

In the present study, A mathematical model describing the complete stress-strain curve of microconcrete subjected to static and dynamic loadings, has been presented, without entailing too long numerical exploitation. Good agreement is obtained between analytical and experimental results.

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